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RESEARCH DEPARTMENT

THE RELATIVE VISIBILITY OF RANDOM NOISE OVER THE GREY-SCALE

Report No. T-095

(1962/30)

THE BRITISH BROADCASTING CORPORATION
ENGINEERING DIVISION

RESEARCH DEPARTMENT

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SUMMARY

The main factors which influence the relative visibility of random fluctuation noise over the grey-scale of a television display are examined. By applying existing data relating to the perception of small differences in luminance, theoretical relative visibility curves are deduced for noise attributable to three distinct types of source encountered in television systems.

1. INTRODUCTION

In the theoretical analysis of random noise in television systems it is often valuable to know not only the magnitude of the signal-to-noise ratio to be expected at the reproducer input, but also, how the luminance-noise produced will be distributed, in terms of relative visibility, over the available tonal range of the reproducer. Suppose, for instance, that the displayed television picture takes the form of a stepped grey-scale wedge ranging from "black" to "peak white", corresponding to a range of picture signal extending from zero to maximum, then it is usually found that there is a region of the wedge where the luminance-noise is more easily visible.

Four main factors influence the distribution of noise visibility. These are:

(a) The variation in the Fechner fraction $\Delta Y/Y$ with luminance level Y.

(b) The transfer characteristic of the system between the noise source and the displayed picture.

(c) The maximum available luminance contrast in the displayed picture as viewed, (e.g., the effect of ambient illumination on the screen).

(d) The type of noise source.

Taking these factors into account, approximate relative visibility distributions can be deduced which are expected to be qualitatively valid for both monochrome and colour television displays. An analysis has been given by Mertz[1] (1950) which deals with both added noise and noise modulating the signal. Maurice et al[2] (1955) have investigated the visibility of several types of noise associated with television signal-generation equipment. Factor (c), however, was not considered by either of these authors.

2. THE FECHNER FRACTION

It is known that, in visual photometry, the fractional increment in luminance (i.e., Fechner fraction = $\Delta Y/Y$) just detectable between two adjacent fields increases as the luminance level Y decreases. The rate of increase of $\Delta Y/Y$ depends on a number of factors, one important factor being the state of adaptation of the eye. Following Mertz, the empirical data given by Moon and Spencer[3] for the variation in Fechner fraction with luminance level have been used here. The results for two conditions of adaptation are shown by the full-line curves in Fig. 1, where $\Delta Y/Y$ is plotted against Y for the range 0·1 to 20 ft-L (foot lamberts), using logarithmic co-ordinate scales. These threshold curves relate to optical experiments employing a circular object-field concentric with a (larger) test field, the fields subtending angles of 1° and $1\frac{1}{2}^\circ$ at the fovea of the eye, respectively. Curve A is the result obtained when the test field has a black surround and curve B refers to the higher-adaptation condition produced by a surround having a uniform luminance of 10 ft-L. These two states of adaptation can be considered as representing the extreme conditions of view encountered in a television display whose maximum luminance is also 10 ft-L; hence it seems reasonable to assume that the appropriate Fechner threshold curve for a given picture will lie somewhere between the curves A and B shown.

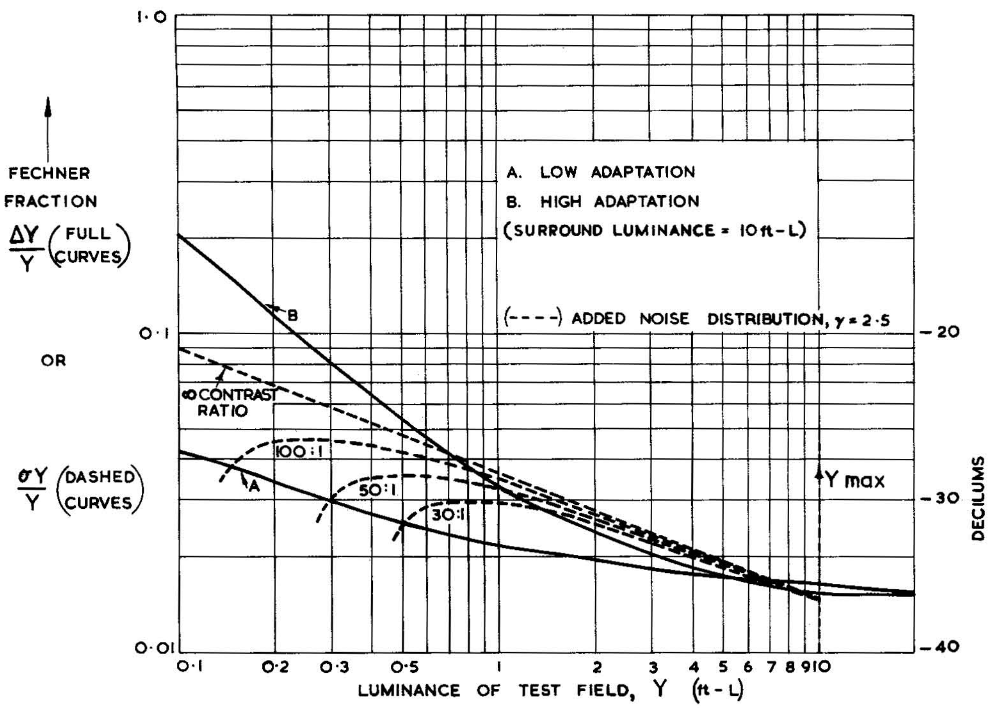

Fig. 1 - Fechner fraction as a function of luminance

——————— Fechner threshold curves, derived from the Moon and Spencer formula, for two states of adaptation of the eye

- - - - - - - Luminance-noise distribution curves for noise added at the television reproducer input (shown for four different maximum contrast ratios).

Although these data refer to luminance discrimination between steady fields of photometric size which are, clearly, different in character from the scintillating "graininess" associated with random noise, it is assumed here (in the absence of more relevant data) that the application of the results is, at least, qualitatively valid.

3. THE DISTRIBUTION OF ADDED NOISE

If the r.m.s. value of the random noise introduced is reasonably small compared with the level of the attendant signal, and the transfer characteristic between the noise source and the displayed picture is known, one may deduce readily, for example, the approximate ratio $\sigma Y/Y$ of the r.m.s. luminance deviation to the mean luminance* as a function of mean luminance. Assuming for the display tube, a simple power-law transfer characteristic of the form,

$$Y - Y_{min} = kE^{\gamma} \tag{1}$$

(where E is the voltage of the picture signal and k and γ are constants) and that a small, but constant, amount of random noise is added to the signal input, we obtain luminance-noise distribution curves of the form shown by the dashed-line curves of Fig. 1. Here $\sigma Y/Y$ is plotted against Y for the various maximum contrast ratios Y_{max}/Y_{min} indicated. The curves all relate to a display tube with $\gamma = 2{\cdot}5$ and $Y_{max} = 10$ ft-L. Increasing or decreasing the amount of noise added to the signal input simply shifts the family of curves vertically on the diagram: the vertical positioning shown in the figure is chosen to coincide with the Fechner threshold curves for easier comparison.

When the maximum picture contrast is not limited by, for instance, ambient illumination of the screen and/or flare originating in the display tube (i.e., when $Y_{min} = 0$ in equation (1)), it will be seen that a straight-line distribution is obtained. The slope of this line is equal to $-1/\gamma$, hence the gamma of the tube is, clearly, an important factor affecting the uniformity of the distribution.

Under normal viewing conditions the maximum available contrast ratio is often determined by the ambient room illumination. The effect on the noise distribution is shown by the curves labelled 100 : 1, 50 : 1 and 30 : 1, respectively, in Fig. 1, which are derived by assuming that sufficient steady ambient illumination falls on the screen, limiting the (otherwise infinite) contrast ratio to the above-mentioned values. For the special case when a linear transfer characteristic exists ($\gamma = 1$ in equation (1)) the distribution for added noise may be shown to be independent of the maximum contrast ratio.

4. RELATIVE VISIBILITY

Referring again to the combined data in Fig. 1, suppose that we select a particular Fechner threshold curve (curve A, say) and that we adjust the magnitude of the added noise so that it is just visible at maximum luminance. Then,

*This quantity is sometimes expressed in "decilums" (= 20 $\log_{10} \sigma Y/Y$) to denote that a ratio of luminance amplitudes is involved. (See Ref. 1.)

from the form of the noise distribution curves, it is clear that there is a range of the grey-scale where the noise will be somewhat above the threshold and, therefore, more easily visible. If, now, the relative attenuation of the noise magnitude required to obtain constant (threshold) visibility at each point in the grey-scale is deduced, we obtain, for the data given in Fig. 1, curves of the form shown by the full lines in Fig. 2. In this figure, the relative attenuation, in decibels, required to maintain constant visibility (low-adaptation threshold) is plotted against relative luminance Y/Y_{max}. For the purpose of description we may regard the relative luminance range, 0•01 to 0•1, as demarcating the black - dark-grey - mid-grey region of the grey scale and the range 0•1 to 1•0 the mid-grey - light-grey - white region. It will be seen (Fig. 2) that for each contrast ratio there is a (broad) maximum to the curve centred in the dark- to mid-grey region of the grey-scale and, further, the effect of reducing the maximum contrast ratio is to shift the maximum of the curve towards the lighter greys.

Relative visibility is a subjective term and its precise relation to the objective measure of the noise amplitude, when the threshold has been exceeded, has not been determined. However, in view of the general logarithmic behaviour of

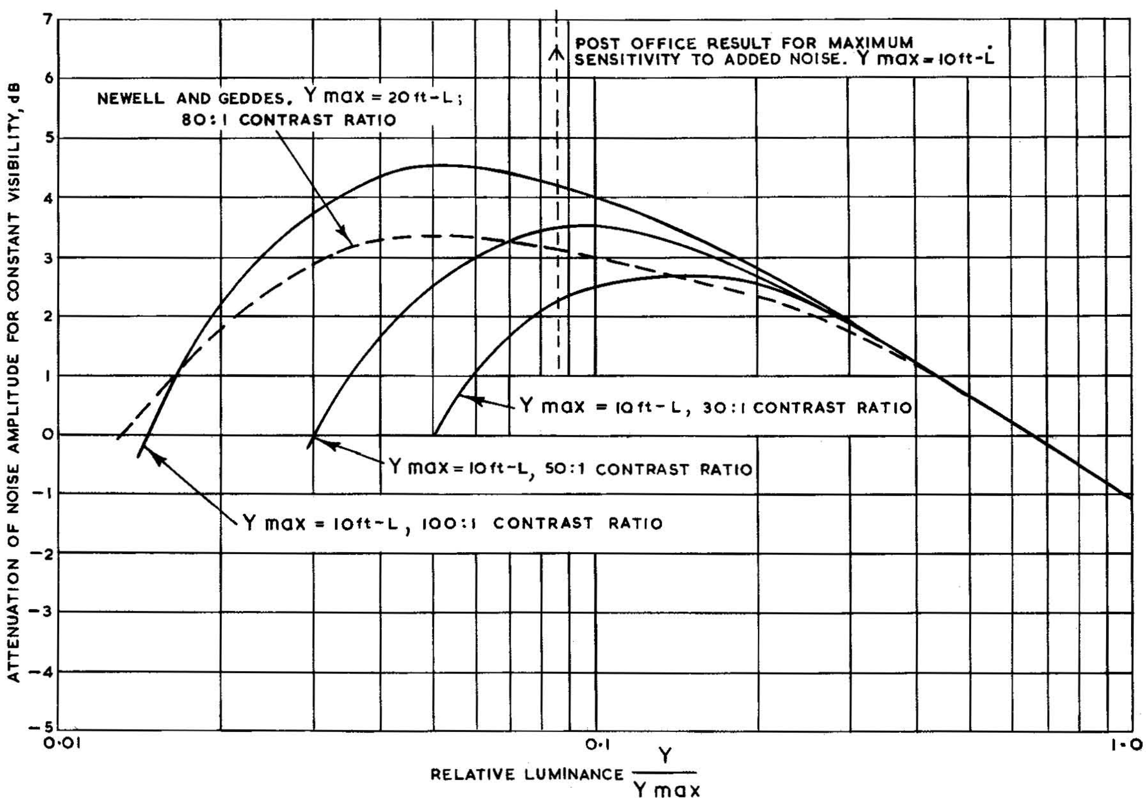

Fig. 2 - Relative visibility curves for noise on a television picture

——————— Added noise (deduced from the data given in Fig. 1) showing the effect of limiting the maximum contrast ratio.

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the eye found in other contrast perception experiments, it seems reasonable to assume that noise visibility is proportional, for a given luminance level, to the logarithm of the ratio of the r.m.s. deviation in luminance σY to the Fechner threshold increment ΔY. Hence, with this assumption, the curves shown in Fig. 2 may be regarded as approximate relative visibility curves.

The dashed-line curve in Fig. 2 is an experimental result obtained by G.F. Newell and W.K.E. Geddes[4] relating to the perception of numerals superimposed on the grey-scale of a test card displayed by a television picture monitor (peak-white luminance at 20 ft-L, and a maximum contrast ratio of 80 : 1). Earlier subjective experiments on the visibility of added "flat" noise over the grey-scale, carried out by the Post Office Engineering Department,[5] showed the region of maximum sensitivity to be centred at 0·86 ft-L with a peak-white luminance at 10 ft-L. There appears to be good qualitative agreement between these experimental results and the deduced visibility curves.

5. OTHER TYPES OF RANDOM NOISE SOURCE

In addition to noise added at the input to the display tube, relative visibility curves have been deduced for two other common types of random noise source encountered in television. The results are shown, together with that obtained for added noise, in Fig. 3, where relative visibility in decilums

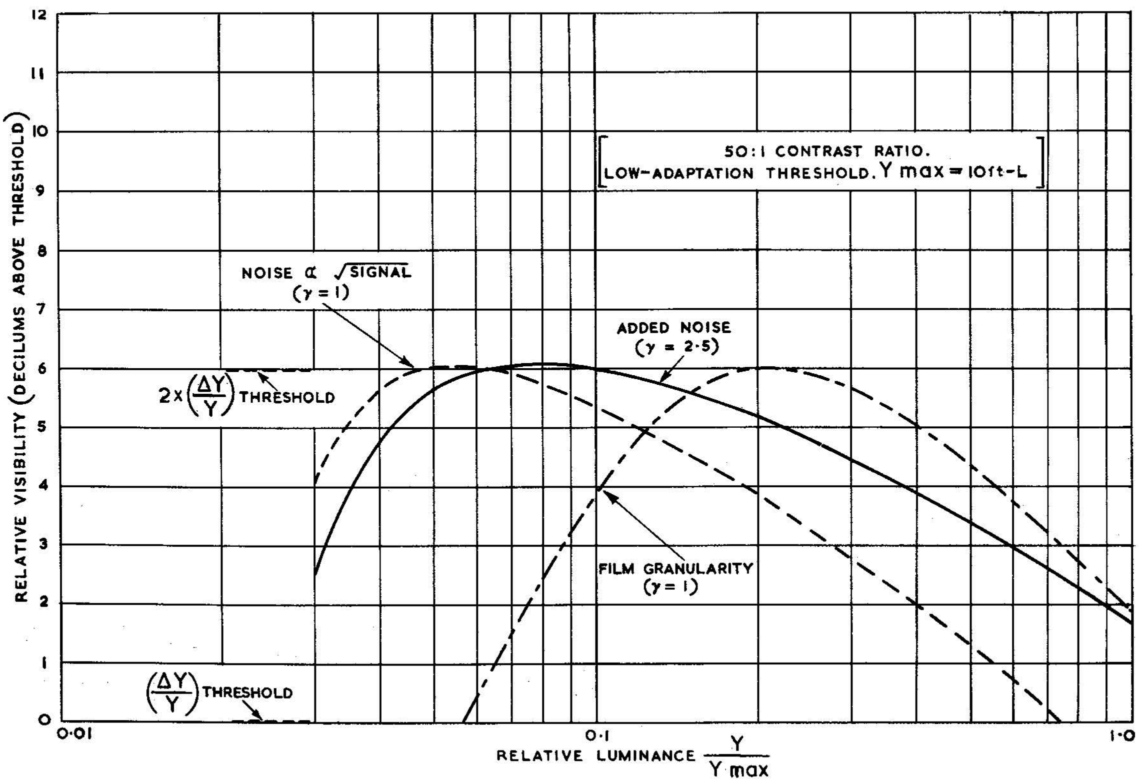

Fig. 3 - Comparison of the relative visibility curves for three types of random noise source

($= 20 \log_{10} \sigma Y/\Delta Y$) is plotted against relative luminance. The dashed-line curve refers to random noise, whose r.m.s. value is proportional to the square root of the signal amplitude (e.g., photo-emission noise), introduced in a linear part of the system (i.e., the overall transfer characteristic is given by equation (1) with $\gamma = 1$). The chain-line curve refers to photographic-film granularity and has been deduced assuming the film to be a normal positive release print of a "grainy" negative and that maximum luminance corresponds to a print density of 0·2 above base. In deducing the curves shown in Fig. 3 an ambient-limited contrast ratio of 50 : 1, a maximum luminance of 10 ft-L and the low-adaptation Fechner threshold were assumed. The three curves are normalized so that the peak visibility level occurs at twice (i.e., 6 decilums above) the just perceptible threshold.

Comparing the three types of noise source, added noise appears to be the most uniformly distributed, with a peak visibility occurring in the dark greys, while for noise proportional to the square root of the signal amplitude there is considerable emphasis in the near blacks. Noise caused by film grain is markedly different in that it is much more visible in the lighter tones of the grey-scale. It should be emphasized, in conclusion, that the relative visibility curves shown in this report will be substantially modified if the noise is inserted at other points in the television chain, where a different overall transfer characteristic between noise source and picture exists. For example, noise added in a linear part of the system (not at the reproducer input) would have a very non-uniform visibility distribution with a sharp maximum in the extreme blacks.

6. ACKNOWLEDGEMENTS

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N.B. This report is a transcript of a paper read at a meeting of the British Institution of Radio Engineers on 14th December 1961.

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